

SYSTEM, APPARATUS, AND METHOD FOR DETECTING A RADAR PULSE USING PATTERN MATCHING

Field of the Invention

This invention relates to detection of radar transmissions using a module in a Wi-Fi transceiver that is configured to detect a radar pulse when the Wi-Fi transceiver is transmitting and receiving data in the 5 GHz Wi-Fi / WLAN frequency band. In particular, the module is configured to detect a radar pulse by analysing a pattern at the transceiver to determine if the pattern exhibits traits of a radar pulse.

Background

As more and more wireless devices are being introduced into the market, larger numbers of devices are compelled to coexist together within a particular frequency band. In the earlier days, nearly all devices that utilized Wi-Fi technology such as personal computers, video games, phones, tablets, smart televisions, etc. utilized the 2.4 GHz radio band. However, as technology improved and as newer schemes such as Peer-to-peer and Wi-Fi direct became standard features on Wi-Fi devices, most Wi-Fi access points now transmit in both 2.4 GHz and 5 GHz frequency bands.

The 5 GHz band is preferred over the 2.4 GHz band as it offers more radio channels; it is less congested and suffers from less interference from other devices (e.g. microwave ovens and Bluetooth transmitters). However, a drawback of operating in the 5 GHz band is that the Wi-Fi and Wireless Local Area Network (WLAN) devices must coexist with radar transmissions that occur in the 5 GHz frequency bands. It is imperative that devices operating in the 5 GHz bands do not interfere with existing radar signals and to this end, stringent requirements have been released by various jurisdictions to address this issue. For example, the Federal Communications Commission (FCC) has released stringent requirements for operating in the Dynamic Frequency Selection (DFS) portion of the 5 GHz band. This is because radar systems such as weather radars or air traffic controls' radars, and other types of radar patterns that are specified in the DFS portion of the 5 GHz band or as specified in the ETSI BRAN (European Telecommunications Standards Institute) (Broadband Radio Access Networks) requirements commonly operate within this spectrum.

The FCC requirements necessitates Wi-Fi and WLAN access points that utilize the 5 GHz to carry out long scan intervals to detect the presence of any radar installations. This is

done by having these devices (e.g., access point) scan the channels for a sufficiently long enough time period to obtain a certain confidence level that no radar is present.

In summary, interference mitigation techniques are required to enable WLAN devices to share these frequency bands with radar systems. The general requirement is that these devices have to detect the probability of interference occurring, identify the radar interfering sources, and avoid using the frequencies used by the radar.

Present proposals from the ETSI BRAN committee provide various simple guidelines for radar detection. The guidelines stipulate that radar signals that only appear at a level above a certain pre-defined threshold have to be detected and avoided. For example, a solution that has been proposed by those skilled in the art uses a simple algorithm to detect instances of signals above the pre-defined threshold during a pre-defined startup listening period. Another solution that has been proposed is that the detection of the radar signal during normal operation should be addressed by periodically suspending all network traffic and listening in startup mode for any instances of signals above the pre-defined threshold level. If signals above the pre-defined threshold level are detected, this then implies that radar signals are present and as such, normal operation of the device should be suspended temporarily.

Despite these guidelines proposed by the various committees, the radar and satellite industries increasingly expect 5 GHz Wi-Fi and WLAN devices to detect radar signals during normal operation. As such, WLAN and Wi-Fi devices are now configured to detect radar when they are both transmitting LAN packets, and when they are idle. This is especially important in areas whereby the usage of radar is prevalent as this will increase the chance of quickly detecting radar sources that are temporarily co-located in an area of operation of the WLAN device, and thereby reduce interference with such radar sources.

Existing solutions typically utilize the WLAN devices' receiver to receive a set of pulses in the relevant frequency band. These pulses are then stored according to their pulse duration, pulse interval and pulse power. The receiver then proceeds to assess the stored pulses to determine if the stored pulse comprises a regular interval pulse (i.e. a pulse with similar intervals between each pulse), a staggered interval pulse (i.e. different pulse intervals for each pair of pulse, not necessarily in ascending or descending intervals) or a non-standard pulse (i.e. neither staggered or regular). In order to determine the type of the stored pulse, the receiver will compare one of the pulse intervals with its immediately

preceding pulse intervals. If the pulse intervals are similar, this implies that the stored pulse is a regular interval pulse. However, if the pulse intervals are different, the difference in the pulse intervals is then compared with a pre-defined list which sets out known patterns in the difference of the pulse intervals. If the receiver determines that the stored pulses comprise a regular interval pulse or a staggered interval pulse, then it is assumed that a radar signal is present.

However, as such methodologies are based on sequential analysis techniques, it will only work if the entire sequence of pulses are correctly detected, received and stored. When the WLAN device encounters radio traffic on the 5 GHz frequency band, there is high possibility that a number of pulses may not be detected as the device may be operating in its transmit mode, or the received pulse and packets may overlap in the time domain, these situations are referred to herein as interference and traffic issues respectively.

For the above reasons, the inventors have identified a need for a method that more efficiently and accurately identifies radar in a WLAN device even if a radar pulse, belonging to a set of transmitted pulses, remains undetected at the receiver due to general interference or traffic issues as described above.

Summary

The above and other problems are solved and an advance in the art is made by the apparatus and methods provided by embodiments in accordance with the invention.

A first advantage of the embodiments in accordance with the invention is that it is possible to identify a radar pulse pattern from a series of collected radar pulses even if one or more of the actual pulses were not detected due to interference issues, or incorrectly received by the device.

A second advantage of embodiments in accordance with the invention is that the invention is able to achieve a higher and faster radar detection rate as compared to existing radar detection methods and systems.

According to a first aspect of the invention, a method for detecting a radar signal using a module communicatively connected to a wireless transceiver is disclosed. Communicatively connected may mean that the module is able to send and receive signals to and from the wireless transceiver and that the module and wireless transceiver may be located within a single equipment. The method comprises obtaining a series of pulse intervals from a series of received signal pulses that each have a similar duration and power,

whereby each pulse interval comprises a time interval between two adjacent signal pulses. The skilled person will be able to determine which pulses can be deemed similar. This may be also based on e.g. knowledge of the possible radar types, or with some knowledge of the deployment scenario. It should be noted that at this stage, the series of pulse intervals may be arranged based on the time order of receipt at the transceiver. The method then identifies at least one primary interval from the series of pulse intervals and proceeds to generate a combined sequence list from a set of predetermined lists using the identified at least one primary interval. A primary interval may be the interval with the lowest value. The method then identifies pulse intervals in the series of obtained pulse intervals that match with pulse intervals in the combined sequence list and determines if a number of the identified matching pulse intervals exceeds a predetermined matching threshold, whereby the received signal pulses are determined to contain a radar signal if the number of identified matching pulse intervals exceeds the predetermined matching threshold. Conversely, or additionally, the method may determine that the detected signal pulses do not comprise a radar signal when the number of the identified matching pulse intervals is less than a predetermined matching threshold.

With reference to the first aspect, the obtaining the series of pulse intervals further comprises organizing the obtained series of pulse intervals sequentially, from a pulse interval that has the smallest value to a pulse interval that has the largest value. An objective of sorting the pulse intervals is that in practice, the method involves the step of identifying the smallest pulse interval and the gaps between each pulse interval in sequence in order to identify the primary intervals. The sorting of the pulse intervals into a sequential order may take place when at least two pulse intervals have been received. An efficient way to effect the sequential ordering of the pulse intervals is to sort the pulse intervals in order each time a relevant new pulse interval is received.

With reference to the first aspect, the identifying the at least one primary interval further comprises determining whether the identified at least one primary interval comprises a valid signal series and determining that the received signal pulses do not contain a radar signal when determined that the identified at least one primary interval is not a valid signal series.

With reference to the first aspect, after the method has determined that the received signal pulses comprises a radar signal, the method further comprises the additional step of verifying whether a type of radar signal is contained in the detected signal pulses. The method verifies that the radar signal is contained in the detected signal pulses when it is

determined that a value of the smallest primary interval exceeds a minimum pulse repetition threshold value and when it is determined that a value of the largest primary interval is lower than a maximum pulse repetition threshold value, whereby the minimum and maximum pulse repetition threshold values are based on an associated radar signal type as specified in the European Telecommunications Standards Institute Broadband Radio Access Networks (ETSI BRAN) requirements. This additional step is advantageous as it confirms that a radar signal, as defined in existing ETSI BRAN requirements, is present in the detected signal pulses.

With reference to the first aspect, the identifying the at least one primary interval from the sequentially organized pulse intervals comprises: identifying pulse intervals that have a value less than a primary interval threshold value, T_{pth} , whereby: $T_{pth} = [(2 \times T_{min}) - tolerance]$ where T_{min} is a pulse interval from the sequentially organized pulse intervals that has the lowest value and *tolerance* is a value between $-10\% \times (2 \times T_{min})$ and $10\% \times (2 \times T_{min})$; determining, from the identified pulse intervals, pulse intervals having a sequential pulse interval increment that exceeds an interval threshold parameter and categorizing the determined signal pulses as primary intervals, whereby the interval threshold parameter is set according to types of radar signals that are to be detected. For example, if ETSI type 6 radar signals are to be detected, the smallest interval defined by ETSI standards for type 6 radar signals is $1/1200 \text{ PPS} = 833 \mu\text{s}$. Hence, a fraction (about 5%) of this smallest interval is set to be the *interval_threshold* parameter. In this example, this means that the *interval_threshold* parameter $= 5\% \times 833 \mu\text{s} \approx 40 \mu\text{s}$.

With reference to the first aspect, the determining whether the identified at least one primary interval comprises a valid signal series may comprise determining from the identified at least one primary interval if there are more than three primary intervals and if it is determined that there are more than three primary intervals, classifying the identified at least one primary interval as an invalid signal series. The ETSI BRAN requirements define staggered radar pulse signals as a series of pulse signals with repeated patterns that have two or three primary intervals. Hence, if four or more primary intervals are obtained, this would imply the likelihood that the radar signal does not comprise a staggered radar pulse signal. Conversely, if two or three primary intervals are obtained, this would imply the likelihood that the radar signal comprises a staggered radar pulse signal.

With reference to the first aspect, the generating the combined sequence list from the set of predetermined lists comprises: selecting from the set of predetermined lists an appropriate predetermined list, whereby predetermined list L_1 is selected if one primary

interval, T_1 , is identified, predetermined list L_2 is selected if two primary intervals, T_1 and T_2 , are identified and predetermined list L_3 is selected if three primary intervals, T_1 , T_2 and T_3 , are identified, where: $L_1 = \{T_1, 2T_1, 3T_1, 4T_1, 5T_1, 6T_1, 7T_1, 8T_1\}$; $L_2 = \{T_1, T_2, T_1+T_2, 2T_1+T_2, T_1+2T_2, 2T_1+2T_2, 3T_1+2T_2, 2T_1+3T_2\}$; and $L_3 = \{T_1, T_2, T_3, T_1+T_2, T_1+T_3, T_2+T_3, T_1+T_2+T_3, 2T_1+T_2+T_3, T_1+2T_2+T_3, T_1+T_2+2T_3\}$.

According to a second aspect of the invention, a wireless transceiver for detecting radar signals is disclosed. The wireless transceiver may be a transceiver configured to send and optionally receive signals in a wireless network, such as a WIFI network. The wireless transceiver also comprises a module, such as an electronic module, that is configured to obtain a series of pulse intervals from a series of received signal pulses that each have a similar duration and power, whereby each pulse interval comprises a time interval between two adjacent signal pulses. It should be noted that at this stage, the signal pulses are arranged based on the time order of receipt at the transceiver. The electronic module is then configured to identify at least one primary interval from the series of pulse intervals and to generate a combined sequence list from a set of predetermined lists using the identified at least one primary interval. After that, the module is configured to then identify pulse intervals in the series of obtained pulse intervals that match with pulse intervals in the combined sequence list. The module is configured to then determine if a number of the identified matching pulse intervals exceeds a predetermined matching threshold, whereby the received signal pulses are determined to contain a radar signal if the number of identified matching pulse intervals exceeds the predetermined matching threshold. Conversely, or additionally, the module may be also configured to determine that the received signal pulses do not comprise a radar signal when the number of the identified matching pulse intervals is less than a predetermined matching threshold.

With reference to the second aspect, the obtaining the series of pulse intervals further comprises organizing the obtained series of pulse intervals sequentially, from a pulse interval that has the smallest value to a pulse interval that has the largest value. An objective of sorting the pulse intervals is that in practice, the method involves the step of identifying the smallest pulse interval and the gaps between each pulse interval in sequence in order to identify the primary intervals. The sorting of the pulse intervals into a sequential order may take place when at least two pulse intervals have been received. An efficient way to effect the sequential ordering of the pulse intervals is to sort the pulse intervals in order each time a relevant new pulse interval is received.

With reference to the second aspect, the identifying the at least one primary interval further comprises the electronic module being configured to determine whether the identified at least one primary interval comprises a valid signal series and to determine that the received signal pulses do not contain a radar signal when determined that the identified at least one primary interval is not a valid signal series.

With reference to the second aspect, after the electronic module has determined that the received signal pulses comprises a radar signal, the electronic module is further configured to verify whether the radar signal is contained in the detected signal pulses. The electronic module verifies that the radar signal is contained in the detected signal pulses when it is determined that a value of the smallest primary interval exceeds a minimum pulse repetition threshold value and when it is determined that a value of the largest primary interval is lower than a maximum pulse repetition threshold value, whereby the minimum and maximum pulse repetition threshold values are based on an associated radar signal type as specified in the European Telecommunications Standards Institute Broadband Radio Access Networks (ETSI BRAN) requirements. This additional step is advantageous as it confirms that a radar signal, as defined in existing ETSI BRAN requirements, is present in the detected signal pulses.

With reference to the second aspect, the identifying the at least one primary interval from the sequentially organized pulse intervals comprises the electronic module being configured to: identify pulse intervals that have a value less than a primary interval threshold value, T_{pth} , whereby: $T_{pth} = [(2 \times T_{min}) - tolerance]$ where T_{min} is a pulse interval from the sequentially organized pulse intervals that has the lowest value and *tolerance* is a value between $-10\% \times (2 \times T_{min})$ and $10\% \times (2 \times T_{min})$; determining, from the identified pulse intervals, pulse intervals having a sequential pulse interval increment that exceeds an interval threshold parameter and categorizing the determined signal pulses as primary intervals, whereby the interval threshold parameter is set according to types of radar signals that are to be detected. For example, if ETSI type 6 radar signals are to be detected, the smallest interval defined by ETSI standards for type 6 radar signals is $1/1200 \text{ PPS} = 833 \mu\text{s}$. Hence, a fraction (about 5%) of this smallest interval is set to be the interval_threshold parameter. In this example, this means that the interval_threshold parameter = $5\% \times 833 \mu\text{s} \sim 40 \mu\text{s}$.

With reference to the second aspect, the determining whether the identified at least one primary interval comprises a valid signal series comprises the electronic module being configured to determine from the identified at least one primary interval if there are more

than three primary intervals and if it is determined that there are more than three primary intervals, classifying the identified at least one primary interval as an invalid signal series. The ETSI BRAN requirements define staggered radar pulse signals as a series of pulse signals with repeated patterns that have two or three primary intervals. Hence, if four or more primary intervals are obtained, this would imply the likelihood that the radar signal does not comprise a staggered radar pulse signal. Conversely, if two or three primary intervals are obtained, this would imply the likelihood that the radar signal comprises a staggered radar pulse signal.

With reference to the second aspect, the generating the combined sequence list from the set of predetermined lists comprises the electronic module being configured to select from the set of predetermined lists an appropriate predetermined list, whereby predetermined list L_1 is selected if one primary interval, T_1 , is identified, predetermined list L_2 is selected if two primary intervals, T_1 and T_2 , are identified and predetermined list L_3 is selected if three primary intervals, T_1 , T_2 and T_3 , are identified, where: $L_1 = \{T_1, 2T_1, 3T_1, 4T_1, 5T_1, 6T_1, 7T_1, 8T_1\}$; $L_2 = \{T_1, T_2, T_1+T_2, 2T_1+T_2, T_1+2T_2, 2T_1+2T_2, 3T_1+2T_2, 2T_1+3T_2\}$; and $L_3 = \{T_1, T_2, T_3, T_1+T_2, T_1+T_3, T_2+T_3, T_1+T_2+T_3, 2T_1+T_2+T_3, T_1+2T_2+T_3, T_1+T_2+2T_3\}$.

The method may be implemented by a computer program or computer program product with computer code or instructions to perform the method on a suitable device, for example, a device receiving the pulses. The device may be a device in a WIFI network such as a wireless transceiver.

The above advantages are provided by embodiments of a device and method in accordance with the invention operating in the following manner.

Brief Description of the Drawings

The above advantages and features in accordance with this invention are described in the following detailed description and are shown in the following drawings:

Figure 1 illustrating a block diagram representative of a system that transmits and receives radio frequency transmissions in the WLAN and Wi-Fi frequency bands in accordance with embodiments of the invention, also illustrating a radar transmitter that transmits radar pulses;

Figure 2 illustrating a block diagram representative of components in an electronic device or server for implementing embodiments in accordance with embodiments of the invention;

Figure 3 illustrating a typical radar signal that may be detected and collected by a WLAN device's receiver in accordance with embodiments of the invention; and

Figure 4 illustrating a flow diagram of a process for detecting a radar pulse pattern from a series of received and collected pulses in accordance with embodiments of the invention.

Detailed Description

This invention relates to an invention in a Wi-Fi or WLAN transceiver that is configured to detect a radar pulse i.e. make a determination about the presence of radar, when the Wi-Fi transmitter is operating in the 5 GHz Wi-Fi frequency spectrum. In particular, a module in the transmitter is configured to detect a radar pulse by detecting the pattern of the radar pulse.

Figure 1 illustrates a block diagram representative of a system that transmits and receives radio frequency transmissions in the WLAN and Wi-Fi frequency bands. It should be noted that in the following description, the terms "WLAN" and "Wi-Fi" are used interchangeably to refer to a network for a device or devices that are configured to carry out wireless data transmission in the 2.4 GHz and/or 5 GHz frequency bands. In particular, system 100 includes a wireless transceiver 115 that includes electronic module 116 that is configured to detect radar signals that may be affected by wireless signals transmitted by wireless transceiver 115. Wireless transceiver 115 comprises a WLAN device that may transmit and/or receive signals in the 2.4 GHz and 5 GHz bands and may comprise an electronic device such as an Access Point (AP), mobile terminal (node) or a station within a greater wireless network. In embodiments of the invention, wireless transceiver 115 may comprise a master device for a wireless network that communicates with client devices such as mobile device 105 and server 120.

As for mobile device 105, this may comprise any electronic device that is capable of transmitting and receiving wireless signals in the 2.4 GHz and 5 GHz frequency bands such as, but not limited to, a mobile phone, a smartphone, a laptop, a personal computer, mobile access points and etc.

Wireless transceiver 115 is also communicatively connected to network server 120 via network 150. One skilled in the art will recognize that network 150 may comprise a wireless network such as a wireless Local Area Network (LAN), Bluetooth, Near Field Communication (NFC), cellular networks, satellite networks, telecommunication networks or Wide Area Networks (WAN). In embodiments of the invention, WLAN is used as an example, although the person skilled in the art will realize that other network deployment scenarios are also possible.

As illustrated in Figure 1, system 100 also includes a radar source 110 that could comprise a stationary source such as a radar transmitter, or it could be a mobile radar source, such as an airplane. Regardless of the type of radar source, Figure 1 illustrates that radar source 110 is operating within the range of wireless transceiver 115. In other words, this means that radar source 110's coverage overlaps with one or more of the coverage areas operated by wireless transceiver 115. An overlap in coverage area is indicated schematically by the dashed ovoid line in Figure 1. This overlap in coverage areas implies that potential radar interference may occur with the WLAN traffic between wireless transceiver 115 and its respective receivers, e.g. mobile device 105 and server 120.

In an embodiment of the invention, wireless transceiver 115 includes electronic module 116 that has been configured to work with the WLAN transceiver in wireless transceiver 115 to detect any interfering signals, determine if the interfering signals comprise radar pulses and possibly identify radar source 110 (if its signature or profile is known), and switch to a channel that is free of the radar interference.

Figure 2 illustrates a block diagram representative of components of an electronic device 200 that is provided within electronic module 116 for implementing embodiments of the invention. One skilled in the art will recognize that the exact configuration of each electronic device provided within the entities or the server may be different and the exact configuration of electronic device 200 may vary and Figure 2 is provided by way of example only.

In embodiments of the invention, device 200 comprises controller 201 and transceiver 255. Transceiver 255 is arranged to interact with other electronic components within electronic device 200 and for this purpose, includes a transmit path comprising transmitter module 260 and amplifier 262 for transmitting signals from electronic device 200 and a receive path comprising a low noise amplifier 272 and a receiver module 270. A person skilled in the art will recognize that transceiver 255 also comprises other components

such as mixers, clock generators, etc. and these components are not described as they are known to those skilled in the art.

Controller 201 is in data communication with transceiver 255 via a bus and controller 201 includes memory 220, Central Processing Unit (CPU) 205 mounted on a circuit board that processes instructions and data for performing the method of this embodiment, an operating system 206, an input/output (I/O) interface 230 for communicating with transceiver 255 and a communications interface, in this embodiment in the form of a network card 250. Network card 250 may, for example, be utilized together with transceiver 255 to send data from electronic device 200 via a wired or wireless network to other processing devices or to receive data via the wired or wireless network. Wireless networks that may be utilized by network card 250 include, but are not limited to, Wireless-Fidelity (Wi-Fi) in the 2.4 GHz and 5 GHz frequency bands at the very least, Bluetooth, Near Field Communication (NFC), cellular networks, satellite networks, telecommunication networks, Wide Area Networks (WAN) and etc.

Memory 220 and operating system 206 are in data communication with CPU 205 via bus 210. The memory components include both volatile and non-volatile memory and more than one of each type of memory, including Random Access Memory (RAM) 220, Read Only Memory (ROM) 225 and a mass storage device 245, the last comprising one or more solid-state drives (SSDs). One skilled in the art will recognize that the memory components described above comprise non-transitory computer-readable media and shall be taken to comprise all computer-readable media except for a transitory, propagating signal. Typically, the instructions are stored as program code in the memory components but can also be hardwired. Memory 220 may include a kernel and/or programming modules such as a software application that may be stored in either volatile or non-volatile memory.

Herein the term “CPU” is used to refer generically to any device or component that can process such instructions and may include: a microprocessor, microcontroller, programmable logic device or other computational device. That is, CPU 205 may be provided by any suitable logic circuitry for receiving inputs, processing them in accordance with instructions stored in memory and generating outputs (for example to the memory components or on display 240). In this embodiment, CPU 205 may be a single core or multi-core processor with memory addressable space. In one example, CPU 205 may be multi-core, comprising—for example—an 8 core CPU.

Referring back to Figure 1, electronic module 116 is configured to detect and optionally store a series of signal pulses. In one embodiment of the invention, wireless transceiver 115 is configured to listen for wireless LAN data packets and it is also controlled through electronic module 116 to detect radar signals (such as those illustrated in Figure 3) while it is waiting to receive and respond to normal WLAN traffic. Upon detecting a series of signal pulses above a pre-defined threshold, electronic module 116 may store and analyse the series of signal pulses to determine whether it is a regular WLAN packet. It should be noted that not all detected signals will comprise radar pulses or WLAN packets. In fact, various types of unrecognized events such as noise fluctuations, collisions between WLAN stations or hidden nodes, co-channel interference, and other non-LAN wireless traffic, such as cordless phone transmissions, and the like may cause a series of pulses to be detected by wireless transceiver 115.

Electronic module 116 will initially capture a series of signal pulses and if electronic module 116 determines that the captured signal pulses form a repetitive pattern, e.g. the signal pulses have a similar duration and power, electronic module 116 may store the entire captured series of signal pulses or may proceed to analyze the entire captured series of signal pulses. One skilled in the art will understand that signal pulses that have a similar power may be plotted as having the same power level or amplitude and signal pulses that have a similar duration may be plotted as having the same width. An example of signal pulses that have similar duration and power are illustrated in Figure 3 as graph 300. It should be noted that the series of pulses may have one or more inherent patterns and graph 300 illustrates an exemplary pattern that may be captured and stored by electronic module 116. In particular, graph 300 represents a series of pulses (having similar power levels and durations) that have been detected and stored whereby the y-axis of the graph represents the power of the pulse (dBm) while the x-axis of the graph represents the time. Also shown are certain undetected pulses which are not stored.

Graph 304 actually comprises a series of two staggered radar pulses from the same radar source, i.e. series 305 which is a series of radar pulses having a T_1 pulse interval set as $T_1 = 850 \mu s$ and series 306 which is a series of radar pulses having a $(T_1 + T_2)$ pulse interval set as $T_2 = 1275 \mu s$. In practice, there will be some variation such as shown in graph 304. These two series have been transmitted as a series of bursts resulting in combined pulse pattern 304 whereby each pulse in the series of pulses is separated by a pulse interval (P). It should be noted that each pulse represents a high-frequency (approximately 5 GHz) sine wave, and may have a duration of approximately one microsecond to five microseconds. The power level of the pulses and the duration of the pulses will vary, depending on the type

of radar signal that is detected and the power levels and durations for the various types of radar signals may be obtained from the ETSI BRAN requirements or the DFS specifications. For example, due to signal interference or signal traffic issues as discussed herein, certain pulses may not be successfully detected by wireless transceiver 115. These pulses are illustrated with dashed lines in Figure 3 and they comprise pulses 310a, 310b, 310c and 310d. Hence, as these four pulses out of the eleven transmitted were not detected by wireless transceiver 115, it can be seen that combined pulse pattern 304 which is stored only contains six pulse intervals, as shown on the horizontal axis.

Electronic module 116 then proceeds to process pulse pattern 304 by carrying out a pattern matching algorithm, such as disclosed in the embodiment disclosed in Figure 4. Ultimately, if electronic module 116 determines that a regular or staggered pattern exists in the pulse pattern 304, this implies that a radar pulse has been detected. Conversely, if a regular or staggered pattern is not identified from pattern 304; electronic module 116 will then disregard the stored pattern and proceed to instruct wireless transceiver 115 to capture another series of pulses as previously described.

As illustrated in Figure 3, a plurality of pulse intervals (P) exists between each of the pulses (i.e. pulses illustrated with solid lines) in combined pulse pattern 304. In particular, if all the pulse intervals from pattern 304 were to be collected and sorted in an ascending order, this would result in the following organized sequence or hereinafter known as original sequence of pulse intervals $Ts_n = \{T_1, T_2, T_3, T_4, T_5, T_6\} = \{850.5, 1260.9, 1277.9, 2094.5, 2132, 2987.3\}$, where n represents the n^{th} pulse interval in the ascending series of pulse intervals. It will be understood that in application, the actual number of pulses will vary and hence so will the pulse intervals. It will also be understood by a person skilled in the art that the sorting of the pulse intervals into a sequential order may take place when at least two pulse intervals have been received and that an efficient way to effect the sequential ordering of the pulse intervals is to sort the pulse intervals in order each time a relevant new pulse interval is added to the series or received by electronic module 116. For brevity, the description hereinafter assumes that the pulse intervals have been sequentially sorted but one skilled in the art will recognize that it may not be necessary for the pulse intervals to be sequentially sorted at this stage provided that a pulse interval having the lowest value may be determined from the series of pulse intervals.

Based on the above original sequence of pulse intervals, electronic module 116 then proceeds to identify the primary intervals, Tp_n in this sequence. This is done by identifying

pulse intervals that satisfy the equation: $T_{s_n} < T_{pth}$ where T_{pth} is the primary interval threshold value.

The primary interval threshold value, T_{pth} , is obtained using the following equation: $T_{pth} = [(2 \times T_{min}) - \text{tolerance}]$ where T_{min} refers to interval T_1 , which is the pulse interval with the lowest pulse interval value. In the sequence above, $T_{min} = 850.5$ and the value of the tolerance is determined as a value between $-10\% \times (2 \times T_{min})$ and $10\% \times (2 \times T_{min})$, i.e. $-10\% \times (2 \times T_{min}) \leq \text{tolerance} \leq 10\% \times (2 \times T_{min})$. In this example, the tolerance value may comprise a value between $-170.1 \leq \text{tolerance} \leq 170.1$ and for this example, is determined as "0", i.e. an ideal scenario. One skilled in the art will recognize that the value of the tolerance may be any value within the range above and is left as a choice to one skilled in the art.

Hence, for the example above, $T_{pth} = 1701$. When this is applied to the equation $T_{p_n} = T_{s_n} < T_{pth}$, this results in T_1 , T_2 and T_3 i.e. $T_{p_n} = \{850.5, 1260.9, 1277.9\}$ where n represents the n^{th} pulse interval in the sequence of primary intervals.

At this stage, electronic module 116 would have identified a certain number of pulse intervals that potentially could be the primary intervals for the original sequence. In this example, this means that three (3) pulse intervals were identified and these intervals potentially could be the primary intervals for the original sequence in this example. An interval_threshold parameter is then applied to further filter these identified pulse intervals with the aim of removing primary intervals that are too close to a previously identified primary interval. The aim of the interval_threshold parameter is to remove intervals that are too close to each other as this implies that these two intervals may be referring to the same primary interval. It also can be said that the interval_threshold parameter is used to filter out intervals that have a sequential interval increment value this is below a certain threshold. It may also be said that this removes primary intervals which are likely duplicates.

In embodiments of the invention, the interval_threshold parameter may be set according to the type of radar pulses that are to be detected. For example, if wireless transceiver 115 is to be operated in the vicinity of mobile radars such as aeroplane radar, electronic module 116 may set the interval_threshold to a value specified by the FCC or ETSI BRAN standards requirements. In other embodiments of the invention, the value of interval_threshold is set based on the measurement accuracy of the transceiver that received and stored the sequence of pulses. In this embodiment of the invention, as ETSI type 6 radar signals are to be detected, the smallest interval defined by ETSI standards for type 6 radar signals is $1/1200 \text{ PPS} = 833 \mu\text{s}$. Hence, a fraction (about 5%) of this smallest

interval is set to be the $\text{interval_threshold}$ value. In this example, this means that $\text{interval_threshold} = 5\% \times 833 \mu\text{s} \approx 40 \mu\text{s}$. One skilled in the art will recognize that this $\text{interval_threshold}$ value will change depending on the type of radar signal that is to be detected.

When the $\text{Interval}_{\text{threshold}}$ value is set as 40, this value is then utilized to filter out primary intervals that are too close to a previously identified primary interval, i.e. from $\text{Tp}_n = \{850.5, 1260.9, 1277.9\}$, this causes primary intervals that have a sequential interval increment of < 40 to be removed. Hence, after the $\text{Interval}_{\text{threshold}}$ has been applied to Tp_n , this results in $\text{Tp}_{n_ \text{Interval_threshold}} = \{850.5, 1260.9\}$ as the intervals “1260.9” and “1277.9” were considered to be related to the same primary interval.

At this stage, electronic module 116 may perform a check to ascertain whether more than three (3) primary intervals have been detected. Other ways may be used. If more than three primary intervals were detected, electronic module 116 will inform wireless transceiver 115 that pattern 304 comprises a false detection. It is useful to note that a staggered radar pattern is only defined in ETSI BRAN standards and is defined to comprise of two or three primary intervals only. For this example, it was determined that there are only two primary intervals, T_1 and T_2 as such; electronic module 116 determines that this is not a false detection. Electronic module 116 then proceeds to apply these two primary intervals to a predetermined list L_n to generate a combined sequence list that is then compared with the original sequence. The predetermined list may provide one or more sequences of pulse intervals that are assumed to be the pulse intervals utilized by a real radar transmission source. The predetermined list may be varied, depending on for example possible known radar transmission sequences.

The combined sequence list may be considered to be a regenerated sequence for use as pattern matching basis against the original sequence, in order to give a probability based assessment of whether the combined sequence is the original sequence.

In accordance with embodiments of the invention, predetermined list L_n (where n represents the number of primary intervals) may comprise one, two or three predetermined lists, and the preferred lists are set out as follows:

$$L_1 = \{T_1, 2T_1, 3T_1, 4T_1, 5T_1, 6T_1, 7T_1, 8T_1\};$$

$$L_2 = \{T_1, T_2, T_1+T_2, 2T_1+T_2, T_1+2T_2, 2T_1+2T_2, 3T_1+2T_2, 2T_1+3T_2\}; \text{ and}$$

$$L_3 = \{T_1, T_2, T_3, T_1+T_2, T_1+T_3, T_2+T_3, T_1+T_2+T_3, 2T_1+T_2+T_3, T_1+2T_2+T_3, T_1+T_2+2T_3\}$$

It should be noted that electronic module 116 may only utilize list L_1 to generate the combined sequence list if electronic module 116 determines that the original sequence comprises of only one primary interval, list L_2 to generate the combined sequence if electronic module 116 determines that the original sequence comprises of only two primary intervals and list L_3 to generate the combined sequence if electronic module 116 determines that the original sequence comprises of only three primary intervals. If electronic module 116 determines that the original sequence comprises four or more primary intervals, the generated combined sequence list would be empty as there are no such predetermined lists for situations where the original sequence comprises four or more primary intervals. In another embodiment, some or each list or parts of each list may be stored and a lookup operation performed.

It should also be noted that when the combined sequences are generated based on $L_1 - L_3$ above, certain measurement errors may be tolerated for each of the individual values generated. For example, if the $\text{Interval}_{\text{threshold}}$ value was previously set as 40 μs , this tolerance may be applied to each of the pulse intervals in the combined sequence as well. However, in another embodiment of the invention, the tolerance may be set based on the limitations of wireless transceiver 116. Assuming that the tolerance was chosen to be 40 μs , this results in pulse intervals T_1+T_2 having $\pm 80 \mu\text{s}$ error would then be considered acceptable, for $2T_1+T_2$, having $\pm 120 \mu\text{s}$ error would then be considered acceptable and etc. In embodiments of the invention, the tolerance may be set as 10% of the smallest measured primary interval. Hence, in this example, the tolerance may also be set as $\pm 85.05 \mu\text{s}$.

In the example above, as the primary intervals of the original sequence, i.e. $\text{Tp}_{\text{n_Interval_threshold}}$, comprises of only Tp_1 and Tp_2 which are {850.5, 1260.9}, this means that electronic module 116 will utilize list L_2 . Electronic module 116 then applies T_1 and T_2 with list L_2 and this generates the following combined sequence list: {**850.5 $\pm$ 40**, **1260.9 $\pm$ 40**, **2111.4 $\pm$ 80**, **2961.9 $\pm$ 120**, 3372.3 $\pm$ 120, 4222.8 $\pm$ 160, etc.}. When this combined sequence list is compared with the original sequence of pulse intervals for pattern 304, i.e. $\{T_1, T_2, T_3, T_4, T_5, T_6\} = \{850.5, 1260.9, 1277.9, 2094.5, 2132, 2987.3\}$, it can be seen that all the values in pattern 304 match with the values in the combined sequence list, i.e. "**850.5 $\pm$ 40**, **1260.9 $\pm$ 40**, **2111.4 $\pm$ 80**, **2961.9 $\pm$ 120**."

In ideal embodiments of the invention, if all the original sequence of pulse intervals matches with the intervals in the combined sequence list, this implies that a radar signal has been detected. However, in other embodiments of the invention, it can also be said that if the number of matches are equal to or exceeds a predetermined match_threshold , this

implies a likelihood that a radar signal has been detected. For this example, if the match_threshold value was set as four, this implies that pattern 304 comprises a radar pulse (as there are six matches) and as such, electronic module 116 would inform wireless transceiver 115 that a radar pulse has been detected.

In a further embodiment of the invention, electronic module 116 may carry out a further verification step to verify whether a radar pulse has been detected. In this embodiment, as two primary intervals were detected (T_{p_n}), electronic module 116 will be configured to use these two primary intervals to check whether the value of $T_{p_1} > Th_{min}$ and whether $T_{p_2} < Th_{max}$ whereby the values of Th_{min} (interval_min) and Th_{max} (interval_max) are obtained from ETSI and FFC standards and are typically selected based on the type of radar signal that is to be detected.

In this embodiment of the invention, the values of Th_{min} and Th_{max} may be obtained from the ETSI standard titled "ETSI EN 301 893 V1.1.1 (2012-06)" which defines that when there are 2 or 3 different Pulse Repetition Frequency (PRF) radar test signals, the minimum PRF is 400 and the maximum PRF is 1200 (i.e. interval_min = 833 μ s and interval_max = 2500 μ s) or the minimum PRF is 300 and the maximum PRF is 400 (i.e. interval_min = 2500 μ s and interval_max = 3333 μ s). For the example above, Th_{min} is 833 μ s and Th_{max} is 2500 μ s. Hence, for the example above, as T_{p_1} and T_{p_2} are 850.5 and 1260.9 respectively, these two values satisfy the criteria above. Parameters of exemplary radar test signals as obtained from the above ETSI standard are illustrated in Table 1 below.

The above device may be implemented in a system comprising at least the wireless transceiver, the electronic module and a radar source.

In accordance with an embodiment of the invention, a corresponding method for a wireless transceiver to determine if a sequence of pulse intervals (optionally stored) is associated with a radar pulse transmission comprises the following steps, which are more optimally performed in the following order:

Step 1, obtaining a series of pulse intervals from a series of received signal pulses that each have a similar duration and power, whereby each pulse interval comprises a time interval between two adjacent signal pulses;

Step 2, identifying at least one primary interval from the series of pulse intervals;

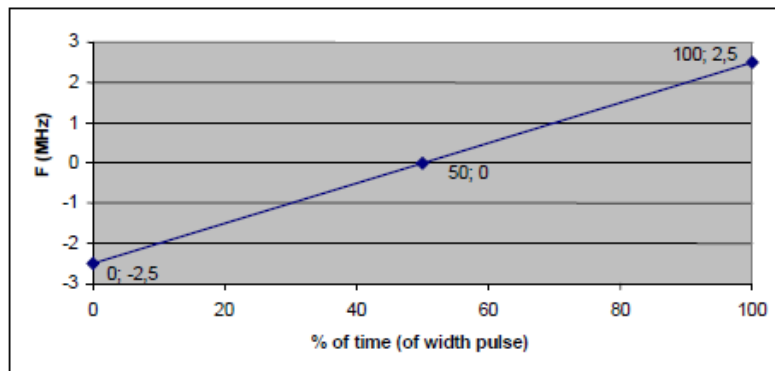
Step 3, generating a combined sequence list from a set of predetermined lists using the identified at least one primary interval;

Step 4, identifying pulse intervals in the series of obtained pulse intervals that match with pulse intervals in the combined sequence list and determining if a number of the identified matching pulse intervals exceeds a predetermined matching threshold, whereby the received signal pulses are determined to likely contain a radar signal if the number of identified matching pulse intervals exceeds the predetermined matching threshold.

Radar test signal # (see notes 1 to 3)	Pulse width W [μ s]		Pulse repetition frequency PRF (PPS)		Number of different PRFs	Pulses per burst for each PRF (PPB) (see note 5)
	Min	Max	Min	Max		
1	0,5	5	200	1 000	1	10 (see note 6)
2	0,5	15	200	1 600	1	15 (see note 6)
3	0,5	15	2 300	4 000	1	25
4	20	30	2 000	4 000	1	20
5	0,5	2	300	400	2/3	10 (see note 6)
6	0,5	2	400	1 200	2/3	15 (see note 6)

NOTE 1: Radar test signals 1 to 4 are constant PRF based signals. See figure D.1. These radar test signals are intended to simulate also radars using a packet based Staggered PRF. See figure D.2.

NOTE 2: Radar test signal 4 is a modulated radar test signal. The modulation to be used is a chirp modulation with a $\pm 2,5$ MHz frequency deviation which is described below.



NOTE 3: Radar test signals 5 and 6 are single pulse based Staggered PRF radar test signals using 2 or 3 different PRF values. For radar test signal 5, the difference between the PRF values chosen shall be between 20 PPS and 50 PPS. For radar test signal 6, the difference between the PRF values chosen shall be between 80 PPS and 400 PPS. See figure D.3.

NOTE 4: Apart for the Off-Channel CAC testing, the radar test signals above shall only contain a single burst of pulses. See figures D.1, D.3 and D.4. For the Off-Channel CAC testing, repetitive bursts shall be used for the total duration of the test. See figures D.2 and D.5. See also clauses 4.7.2.2, 5.3.8.2.1.3.1 and 5.3.8.2.1.3.2.

NOTE 5: The total number of pulses in a burst is equal to the number of pulses for a single PRF multiplied by the number of different PRFs used.

NOTE 6: For the CAC and Off-Channel CAC requirements, the minimum number of pulses (for each PRF) for any of the radar test signals to be detected in the band 5 600 MHz to 5 650 MHz shall be 18.

Table 1: ETSI EN 301 893 V1.1.1 (2012-06)

In order to provide such a method, a process is needed for a device to determine if a detected series of signal pulses is associated with a radar pulse transmission. The following

description and Figure 4 describe embodiments of processes that provide processes in accordance with this invention. Reference may also be made to the embodiments about the aforesaid device and module as described and illustrated herein.

Figure 4 illustrates process 400 that is performed by an electronic module communicatively connected to a Wi-Fi / WLAN device or a wireless transceiver to determine if a detected series of signal pulses is associated with a radar pulse transmission. Figure 4 may illustrate aspects of the 4 step method.

Process 400 begins at step 405 with process 400 selecting, from signal pulses that are detected by the wireless transceiver, a series of signal pulses that each have a similar duration and power. Process 400 then identifies from the series of signal pulses a series of pulse intervals whereby each identified pulse interval comprises a time interval between two adjacent signal pulses. Process 400 may then sequentially sort or organize the detected pulse intervals into an original sequence of pulse intervals e.g. in ascending order. Alternatively, process 400 may not sequentially organize the pulse intervals at step 405 and may instead ascertain the pulse interval that has the lowest value in the series. Other orders or arrangements may be used provided that the comparison of pulse intervals is aware of the configured order.

Process 400 then uses a predefined tolerance value and a predefined `interval_threshold` value to filter out at least one primary pulse interval from the original sequence of pulse intervals. This is done by process 400 at step 410.

At step 415, process 400 then optionally performs the step of determining from the at least one primary pulse interval whether the detected series of signal pulses may possibly include radar pulse transmissions. If process 400 determines that the detected series of signal pulses may not possibly include a radar pulse transmission, process 400 then ends. Process 400 achieves this by determining whether the identified at least one primary interval comprises a valid signal series. In this embodiment this is done by determining from the identified at least one primary interval if there are more than three primary intervals and if it is determined that there are more than three primary intervals, process 400 then classifies the identified at least one primary interval as an invalid signal series. When classified as an invalid signal series, this implies that the series of signal pulses does not include radar pulse transmissions.

Conversely, if process 400 determines that it could be a radar pulse transmission, i.e. when the identified at least one primary interval is classified as a valid signal series, process

400 then proceeds to step 420. It should be noted that process 400 may skip step 415 and proceed to step 420 directly from step 410 instead.

At step 420, process 400 then generates a combined sequence list (refer to embodiment and disclosure of Figure 3) based on the number of identified primary pulse intervals. Process 400 then identifies from the combined sequence list and the original sequence the pulse intervals that appear in both lists.

At step 425, if the number of matches is less than a predefined threshold, process 400 will then end. If the number of matches exceeds the predefined threshold, process 400 will then proceed to step 430 instead. At this step, process 400 will then confirm that a radar pulse transmission has been detected and process 400 will then end.

The above is a description of embodiments of an apparatus and method in accordance with the present invention as set forth in the following claims. Whilst certain features of the invention have been illustrated and described herein, many modifications, substitutions, changes and equivalents will now occur to those of ordinary skill in the art. It is therefore to be understood that the appended claims are intended to cover all such modifications and changes as fall within the true spirit of the invention.

CLAIMS:

1. A method for detecting a radar signal using a module communicatively connected to a wireless transceiver, the method comprising:
 - obtaining a series of pulse intervals from a series of received signal pulses wherein each signal pulse comprises a predetermined duration and power level, whereby each pulse interval comprises a time interval between two adjacent signal pulses;
 - identifying at least one primary interval from the series of pulse intervals;
 - generating a combined sequence list from a set of predetermined lists using the identified at least one primary interval;
 - identifying pulse intervals in the series of obtained pulse intervals that match with pulse intervals in the combined sequence list and determining if a number of the identified matching pulse intervals exceeds a predetermined matching threshold, whereby the received signal pulses are determined to contain a radar signal if the number of identified matching pulse intervals exceeds the predetermined matching threshold.
2. The method according to claim 1, whereby the obtaining the series of pulse intervals further comprises organizing the obtained series of pulse intervals sequentially.
3. The method according to claim 1 or 2, wherein the identifying the at least one primary interval further comprises determining whether the identified at least one primary interval comprises a valid signal series and determining that the received signal pulses do not contain a radar signal when determined that the identified at least one primary interval is not a valid signal series.
4. The method according to any of claims 1 to 3 further comprising:
 - verifying the radar signal in the series of received signal pulses if it is determined that a value of a smallest primary interval exceeds a minimum pulse repetition threshold value and if it is determined that a value of a largest primary interval is lower than a maximum pulse repetition threshold value,
 - whereby the minimum and maximum pulse repetition threshold values are based on an associated radar signal types that are to be detected and as specified in

the European Telecommunications Standards Institute Broadband Radio Access Networks (ETSI BRAN) requirements.

5. The method according to any of claims 2 to 4 wherein the identifying the at least one primary interval from the series of pulse intervals comprises:

identifying pulse intervals that have a value less than a primary interval threshold value, T_{pth} , whereby:

$$T_{pth} = [(2 \times T_{min}) - tolerance]$$

where T_{min} is a pulse interval from the series of pulse intervals that has the lowest value and *tolerance* is a value between $-10\% \times (2 \times T_{min})$ and $10\% \times (2 \times T_{min})$;

determining, from the identified pulse intervals, pulse intervals having a sequential pulse interval increment that exceeds an interval threshold parameter and categorizing the determined signal pulses as the at least one primary interval,

whereby the interval threshold parameter is set according to types of radar signals that are to be detected.

6. The method according to claim 3, or any of claims 4 to 5 as dependent on claim 3, wherein the determining whether the identified at least one primary interval comprises a valid signal series comprises:

determining from the identified at least one primary interval if there are more than three primary intervals and if it is determined that there are more than three primary intervals, classifying the identified at least one primary interval as an invalid signal series.

7. The method according to any of claims 1 to 6 wherein the generating the combined sequence list from the set of predetermined lists comprises:

selecting from the set of predetermined lists an appropriate predetermined list, whereby predetermined list L_1 is selected when the at least one primary interval comprises one primary interval, T_1 , predetermined list L_2 is selected when the at least one primary interval comprises two primary intervals, T_1 and T_2 , and predetermined list L_3 is selected when the at least one primary interval comprises three primary intervals, T_1 , T_2 and T_3 , are identified, where:

$$L_1 = \{T_1, 2T_1, 3T_1, 4T_1, 5T_1, 6T_1, 7T_1, 8T_1\};$$

$$L_2 = \{T_1, T_2, T_1+T_2, 2T_1+T_2, T_1+2T_2, 2T_1+2T_2, 3T_1+2T_2, 2T_1+3T_2\}; \text{ and}$$

$$L_3 = \{T_1, T_2, T_3, T_1+T_2, T_1+T_3, T_2+T_3, T_1+T_2+T_3, 2T_1+T_2+T_3, T_1+2T_2+T_3, T_1+T_2+2T_3\}.$$

8. A wireless transceiver for detecting radar signals comprising:
 - an electronic module configured to:
 - obtain a series of pulse intervals from a series of received signal pulses wherein each signal pulse comprises a predetermined duration and power level, whereby each pulse interval comprises a time interval between two adjacent signal pulses;
 - identify at least one primary interval from the series of pulse intervals;
 - generate a combined sequence list from a set of predetermined lists using the identified at least one primary interval;
 - identify pulse intervals in the series of obtained pulse intervals that match with pulse intervals in the combined sequence list and determine if a number of the identified matching pulse intervals exceeds a predetermined matching threshold, whereby the received signal pulses are determined to contain a radar signal if the number of identified matching pulse intervals exceeds the predetermined matching threshold.
9. The wireless transceiver according to claim 8, whereby the obtaining the series of pulse intervals further comprises the electronic module being configured to organize the obtained series of pulse intervals sequentially.
10. The wireless transceiver according to claim 8 or 9, wherein the identifying the at least one primary interval further comprises the electronic module being configured to determine whether the identified at least one primary interval comprises a valid signal series and to determine that the received signal pulses do not contain a radar signal when determined that the identified at least one primary interval is not a valid signal series.
11. The wireless transceiver according to any of claims 8 to 10 further comprising the electronic module being configured to:
 - verify the radar signal in the series of received signal pulses if it is determined that a value of a smallest primary interval exceeds a minimum pulse repetition threshold value and if it is determined that a value of a largest primary interval is lower than a maximum pulse repetition threshold value,

whereby the minimum and maximum pulse repetition threshold values are based on an associated radar signal types that are to be detected and as specified in the European Telecommunications Standards Institute Broadband Radio Access Networks (ETSI BRAN) requirements.

12. The wireless transceiver according to any of claims 9 to 11 wherein the identifying the at least one primary interval from the series of pulse intervals comprises the electronic module being configured to:

identify pulse intervals that have a value less than a primary interval threshold value, T_{pth} , whereby:

$$T_{pth} = [(2 \times T_{min}) - tolerance]$$

where T_{min} is a pulse interval from the series of pulse intervals that has the lowest value and *tolerance* is a value between $-10\% \times (2 \times T_{min})$ and $10\% \times (2 \times T_{min})$;

determine, from the identified pulse intervals, pulse intervals having a sequential pulse interval increment that exceeds an interval threshold parameter and to categorize the determined signal pulses as the at least one primary interval,

whereby the interval threshold parameter is set according to types of radar signals that are to be detected.

13. The wireless transceiver according to claim 10, or any of claims 11-12 as dependent on claim 10, wherein the determining whether the identified at least one primary interval comprises a valid signal series comprises the electronic module being configured to:

determine from the identified at least one primary interval if there are more than three primary intervals and if it is determined that there are more than three primary intervals, classify the identified at least one primary interval as an invalid signal series.

14. The wireless transceiver according to any of claims 8 to 13 wherein the generating the combined sequence list from the set of predetermined lists comprises:

selecting from the set of predetermined lists an appropriate predetermined list, whereby predetermined list L_1 is selected when the at least one primary interval comprises one primary interval, T_1 , predetermined list L_2 is selected when the at least one primary interval comprises two primary intervals, T_1 and T_2 , and predetermined list L_3 is selected when the at least one primary interval comprises three primary intervals, T_1 , T_2 and T_3 , are identified, where:

$$L_1 = \{T_1, 2T_1, 3T_1, 4T_1, 5T_1, 6T_1, 7T_1, 8T_1\};$$

$L_2 = \{T_1, T_2, T_1+T_2, 2T_1+T_2, T_1+2T_2, 2T_1+2T_2, 3T_1+2T_2, 2T_1+3T_2\}$; and

$L_3 = \{T_1, T_2, T_3, T_1+T_2, T_1+T_3, T_2+T_3, T_1+T_2+T_3, 2T_1+T_2+T_3, T_1+2T_2+T_3, T_1+T_2+2T_3\}$.